Objective

Predict preoperatively the maximum extent to which direct stimulation therapy can propagate through an epileptic circuit for stabilizing refractory focal-onset epilepsy.

Strategy

Create a computationally iterative intensive model to predict activated tracts.

I. Visualization of the Epileptic Circuit

A. Diagnostic Imaging

B. 3D SPECT

C. 3D SPECT

D. 3D SPECT

E. 3D SPECT

F. 3D SPECT

G. 3D SPECT

II. Virtual Positioning of Depth Electrode (Model)

A. An SPECT MRI was used to create a patient-specific 3D model

B. Manual segmentation was performed: Blue=CSF, Grey=Grey Matter (GM), White=White Matter (WM)

C. A CAD electrode model that consisted of four conductive cylinders separated by insulators was created.

D. The virtual electrode was placed in the right temporal lobe near the spIDTI and SISCOM signals, at the white-grey matter interface.

E. Likewise, a virtual electrode was placed in the left frontal lobe.

III. FEM and Activation Function to Predict VOCA (Model)

A. A FEM Mesh with tetrahedral elements was created from the segment- ed brain-electrode model. This mesh was used to simulate the electric potential (EP) and E Field distribution during a bipolar stimulation of 4.3 mA considering the following isotropic conductivities (WM=0.15 S/m, GM=0.06 S/m, CSF=1.79 S/m)

B. The DTI datasets were used to create a vector field of Axon Bundle Directionality. (Axon Bundle Directionality)

C. An ‘activation function’ (AF) was used to identify Areas of depolarization (AF>0) and hyperpolarization (AF<0). The AF was calculated considering the relationship between the magnitude of the E Field, Direction of the E Field, and Axon Bundle Directionality. (Second directional derivative of the electric potential in the direction of axons)

D. A threshold of ±24 mV/mm² was applied to the values of the activation function to create 3D Regions of Interest (ROIs) or seeds that defined the VOCA solution around the electrodes.

IV. Modulated Circuit Tractography (Model) and OR Electrode Placement

A. The pre-implant MCT is shown: The ROIs that were obtained from the activation function were exported to a tractography package and were used to filter tracts that entered regions of depolarization (red and orange) and tracts that entered regions of hyperpolarization (blue and light blue)

B. Stereotactic implantation of the depth electrodes is shown. This implantation was guided by our pre-implant model.

V. Post-Implant Validation (Diagnostic Imaging)

Subtracted Activated SPECT (SAS) was used to validate our pre-implant model: This technique captured transient blood flow changes during delivery of neurostimulation therapy using a high therapeutic charge density delivered through adjacent electrode contacts without generating an after-discharge.

A. The pre-implant model predicting the influenced tracts due to stimulation in contacts 1-2 from the left frontal electrode is shown.

B. SAS regions of hypoperfusion (Numbers indicate areas near the predicted tractography map)

C. SAS regions of hyperperfusion (Numbers indicate areas near the predicted tractography map)

D. ECGs recorded using the implanted RNS system demonstrating the propagation between the left frontal and right temporal epileptic sources interconnected by white matter as the model predicted.

Conclusion

This pre-implant modeling system offers the potential for predicting optimal electrode lead implant sites with a limited set of contacts for modulating the maximal extent of refractory epileptogenic network.